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EFFECT ON VARIATION IN LOAD FACTOR ON STRUCTURAL WEIGHT OF WINGS

(AIRPLANE SECTION, S. & A. BRANCH)

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EFFECT OF VARIATION IN LOAD FACTOR ON STRUCTURAL WEIGHT OF WINGS.

INTRODUCTION.

The object of this investigation is to determine the effect of variations in load factor or useful load upon the sizes and weights of the various parts of the wings.

Assuming the formulas used by the Air Service for the solution of lift trusses and the design of spars and struts to be correct, a definite relationship is established between the useful load and the sizes of members so that it is possible for the designer to predict the resultant sizes and weights due to variations in the useful load.

It is shown that with the present methods of design the area of the spar is of first importance and that within certain limits the area of the routed spars may be arranged without regard to the effect upon the moment of inertia.

The investigation is conducted throughout in terms of the load factor, but by a simple computation the result of changing the weight of useful load instead of the load factor may be estimated.

Two sets of computations are made, one for the R. A. F.-15 section and one for the U. S. A.-27 section, with the wing areas, aspect ratios, gap chord ratio, stagger and weights the same in each case, thus showing any difference in effect on a thin wing and on a moderately thick one.

Consideration of the subject will show that the weight of the covering will not be affected by variation in the load factor, and that the weight of the loading and trailing edges, ribs, drag wires, etc., will be subject to little if any change. The main struts and spars will change in weight and the total weight will change in proportion. This study is therefore limited to the lift trusses.

The stresses in a typical lift truss under a load factor of 1 are computed, multiplied by various load factors, trusses designed for the resulting stresses, and the weights compared.

CONCLUSIONS.

1. The area of spars varies directly with the load factor.
2. The area of struts varies with the load factor and the increase in area is at a slightly smaller rate than the increase in load factor.
3. The weights of the lift truss members vary with their respective areas, and therefore increase at a rate slightly less than that of the load factor.
4. In considering changes in design necessitated by changes in useful load it will be on the safe side to assume that the areas and weights of members of the lift trusses vary directly with the per cent increase in the load factor, and for small increases the error will be negligible.
5. If the spars are designed as light as is consistent with good practice, small increases in useful load with the thicker wing sections may be met by decreasing the routing.
6. The structural weight of wings varies with the load factor, but does not increase as rapidly as the load factor.
7. When an increase of useful load is made in an airplane, it is safe to predict that the sizes and weights will increase in proportion, though the design of the members should be checked before the new sizes are given final approval. This prediction should give fairly accurate sizes, but will give weights that are heavier than they are found to be when the design is checked.

ASSUMPTIONS.

1. In this investigation two flight conditions were considered, high incidence and low incidence.
2. The following assumptions were made with respect to the location of the center of pressure, the angle of incidence, and the value of L/D:

U. S. A. 27.

Flight condition.	Angle of incidence.	L/D.	Position of center of pressure.
	°		*Per cent.*
High incidence	16	9.2	27.4
Low incidence	−2	7.8	63.4

R. A. F. 15.

Flight condition.	Angle of incidence.	L/D.	Position of center of pressure.
	°		*Per cent.*
High incidence	12	10.7	29.0
Low incidence	0	8.1	44.3

3. The standard decrease in loading on the wing tips was assumed.
4. The lower wing was assumed to be 86 per cent as efficient as the upper wing in high incidence and 87 per cent as efficient as the upper wing in low incidence, in accordance with division of load between wings as recommended in article 44 of "Structural analysis and design of airplanes."
5. The wing tips were assumed to be square.
6. The spars were assumed to be hinged at the cabane struts.
7. The lift wires were crossed so that their drag effect would relieve the direct stresses in the spars.
8. The weight of the wings was assumed at 1 pound per square foot and the gross wing loading was assumed at 8 pounds per square foot in computing the stresses in the struts and spars. No correction of the stresses was made to allow for the actual weights of each design.
9. The spars were assumed to be at 12 per cent and 67 per cent of the chord.

10. The aerodynamic characteristics assumed for the U. S. A.-27 section were obtained from the wind tunnel tests at Massachusetts Institute of Technology in November, 1920; those for the R. A. F.-15 section were obtained from the wind tunnel test at Massachusetts Institute of Technology in December, 1919.

11. The location of the outer strut, bay 1-2, and cantilever length were determined by the recommended proportions in article 34 of "Structural analysis and design of airplanes."

12. The drag truss was divided into three panels between the cabane and outer struts.

GENERAL DATA.

Weight of airplane, without wings	2,400 lbs.
Total span of wings	31.5 ft.
Gap	68 in.
Chord of both wings	68 in.
Stagger	+13.6 in.
Length of center section, both wings	30 in.
Length of bay, both wings	110 in.
Length of cantilever section, both wings	64 in.
Area of upper wing	178.6 sq. ft.
Area of lower wing	164.4 sq. ft.
Weight of wings	343 lbs.
Distance from leading edge to front spar	8.16 in.
Distance from leading edge to rear spar	45.56 in.

COMPUTATIONS.

1. The stresses, moments, etc., in the lift trusses are computed for a load factor of 1.0 according to the method in Chapter III of "Structural analysis and design of airplanes," the distribution between the front and rear lift trusses effected, and the direct stress in the spars corrected for the drag truss stresses.

2. Multiplying by the various load factors, we have the moments, shears, stresses, etc., as shown in Tables I and II.

3. The spars were designed for both the U. S. A.-27 section and the R. A. F.-15 section for the stresses, moments, etc., resulting at the various load factors, and the sizes and weights are shown in Tables III, IV, V, VI, VII, and VIII, the method in article 174 of "Structural analysis and design of airplanes" being used.

4. The struts were designed for the loads at the different load factors with sizes as shown in Tables IX and X. The method in Article 91, of "Structural analysis and design of airplanes" was used, combined with Euler's formula for pin-ended columns:

$$P=\frac{\pi^2EI}{L^2} \text{ or } I=\frac{PL^2}{\pi^2E}$$

Assuming a standard streamline wood strut with a fineness of 4, with L=the length of the strut cross section and D the width.

$$I=.0432LD^3$$

$$\text{As } L=4D$$

$$I=.1728D^4$$

$$A=.730LD=2.92D^2$$

$$A^2=8.53D^4 \text{ and } \frac{A^2}{49.34}=.1728D^4$$

$$\text{Then } I=\frac{A^2}{49.34}$$

$$\text{Then } \frac{A^2}{49.34}=\frac{PL^2}{\pi^2E} \text{ and } A=.001768\times L\times\sqrt{P}$$

where A=cross sectional area,
L=length of strut, and
P=comp. in strut.

5. Curves were plotted showing the variation of the cross sectional area of the spars in the routed portion in terms of the load factor (see Fig. 1).

6. Curves showing the variation in weight of the spars in terms of the load factor were plotted (see Fig. 2). In computing these weights it was assumed that there would be a 10-inch unrouted length at the strut points, a 12-inch unrouted length at the wing tips, and 5 inches was subtracted from each 12-inch unrouted portion at the wing tips to allow for the taper of the spars at that point. The spars were considered to be of spruce and to weigh 27 pounds per cubic foot.

7. Curves were plotted showing the variation of the cross sectional area of the outer struts in terms of the load factor, as shown in figure 3.

TABLE I.—*U. S. A.-27.*

	Load factor.	Truss.	Load per cent of W.	Lower spars.		Upper spars.					Drag stress.		Maximum direct stress.	
				M_{1L}	M_{1-2L}	M_{1u}	M_{1-2u}	C_u	S_{+1u}	W/1-inch.	First bay.	Second bay.	At strut.	In span.
High incidence	1.0	Combined	1.00	− 4,780	+ 2,890	− 5,670	+ 3,380	−1,362	+ 265	3.88	....	....	....	....
	1.0	F........	.72	3,442	2,081	4,082	2,434	− 981	191	2.79	− 30	+ 228	− 1,011	− 753
	1.0	R........	.28	1,338	809	1,588	946	− 381	74	1.09	− 228	− 459	− 609	− 840
	5.0	F........	3.60	17,208	10,404	20,412	12,168	−4,903	954	13.97	− 150	+1,140	− 5,053	−3,763
	5.0	R........	1.40	6,692	4,046	7,938	4,732	−1,907	371	5.43	−1,140	−2,295	− 3,047	−4,202
	6.0	F........	4.32	20,650	12,485	24,494	14,602	−5,884	1,145	16.76	− 180	+1,368	− 6,064	−4,516
	6.0	R........	1.68	8,030	4,855	9,526	5,678	−2,288	445	6.52	−1,368	−2,754	− 3,656	−5,042
	7.0	F........	5.04	24,091	14,566	28,577	17,035	−6,861	1,336	19.56	− 210	+1,596	− 7,074	−5,268
	7.0	R........	1.96	9,369	5,664	11,113	6,625	−2,670	519	7.60	−1,596	−3,213	− 4,266	−5,883
	8.0	F........	5.76	27,533	16,646	32,659	19,469	−7,845	1,526	22.35	− 240	+1,824	− 8,085	−6,021
	8.0	R........	2.24	10,707	6,474	12,701	7,571	−3,051	594	8.69	−1,824	−3,672	− 4,875	−6,723
	9.0	F........	6.48	30,974	18,727	36,742	21,902	−8,826	1,717	25.14	− 270	+2,052	− 9,096	−6,774
	9.0	R........	2.52	12,046	7,283	14,288	8,518	−3,432	668	9.78	−2,052	−4,131	− 5,484	−7,563
	10.0	F........	7.20	34,416	20,808	40,824	24,336	−9,806	1,908	27.94	− 300	+2,280	−10,106	−7,526
	10.0	R........	2.80	13,384	8,092	15,876	9,464	−3,811	742	10.86	−2,280	−4,590	− 6,094	−8,404
Low incidence.	1.0	Combined	1.000	− 4,810	+ 2,902	− 5,624	+ 3,360	−1,362	+ 263	3.86	....	....	....	....
	1.0	F........	.065	313	189	366	218	− 89	17	0.25	− 251.4	− 506.4	− 340.4	− 595.4
	1.0	R........	.935	4,497	2,713	5,258	3,142	−1,273	246	3.61	− 28.6	+ 251.4	− 1,301.6	−1,021.6
	4.0	F........	.260	1,251	755	1,462	871	− 354	68	1.00	−1,006	−2,026	− 1,360	−2,380
	4.0	R........	3.740	17,989	10,853	21,034	12,566	−5,094	984	14.44	− 114	+1,006	− 5,208	−4,088
	5.0	F........	.325	1,563	943	1,828	1,092	− 443	85	1.25	−1,257	−2,532	− 1,700	−2,975
	5.0	R........	4.675	22,487	13,567	26,292	15,708	−6,367	1,230	18.05	− 143	+1,257	− 6,510	−5,110
	6.0	F........	.390	1,876	1,132	2,193	1,310	− 531	103	1.51	−1,508	−3,038	− 2,039	−3,569
	6.0	R........	5.610	26,984	16,280	31,551	18,850	−7,641	1,475	21.65	− 172	+1,508	− 7,813	−6,133
	7.0	F........	.455	2,189	1,320	2,559	1,529	− 620	120	1.76	−1,760	−3,545	− 2,380	−4,165
	7.0	R........	6.545	31,481	18,994	36,809	21,991	+8,914	1,721	25.26	− 200	+1,760	− 9,114	−7,154

TABLE II.—*R. A. F.-15.*

Incidence	Load factor.	Truss.	Load, per cent of W.	Lower spars. M_{1L}.	Lower spars. M_{1-2L}.	Upper spars. M_{1u}.	Upper spars. M_{1-2u}.	Upper spars. C_u.	Upper spars. S_{+1u}.	Upper spars. W/1 inch.	Drag stress. First bay.	Drag stress. Second bay.	Maximum direct stress. At strut.	Maximum direct stress. In span.
High incidence.	1.0	Combined	1.000	−4,780	+2,890	−5,670	+3,380	−1,362	+ 265	3.88	....	....	....	....
	1.0	F........	.691	3,303	1,997	3,918	2,336	− 941	+ 183	2.68	− 21	+ 224	− 962	− 717
	1.0	R........	.309	1,477	893	1,752	1,044	− 421	+ 82	1.20	− 224	− 451	− 645	− 872
	5.0	F........	3.455	16,515	9,985	19,590	11,678	−4,706	+ 916	13.41	− 105	+1,120	−4,810	−3,585
	5.0	R........	1.545	7,385	4,465	8,760	5,222	−2,104	+ 409	5.99	−1,120	−2,255	−3,225	−4,360
	6.0	F........	4.146	19,818	11,982	23,508	14,013	−5,647	+1,099	16.09	− 126	+1,344	−5,772	−4,302
	6.0	R........	1.854	8,862	5,358	10,512	6,267	−2,525	+ 491	7.19	−1,344	−2,706	−3,870	−5,232
	7.0	F........	4.837	23,121	13,979	27,426	16,349	−6,588	+1,282	18.77	− 147	+1,568	−6,734	−5,019
	7.0	R........	2.163	10,339	6,251	12,264	7,311	−2,946	+ 573	8.39	−1,568	−3,157	−4,515	−6,104
	8.0	F........	5.528	26,424	15,976	31,344	18,685	−7,529	+1,465	21.45	− 168	+1,792	−7,696	−5,736
	8.0	R........	2.472	11,816	7,144	14,016	8,355	−3,367	+ 655	9.59	−1,792	−3,608	−5,160	−6,976
	9.0	F........	6.219	29,727	17,973	36,262	21,020	−8,470	+1,648	24.13	− 189	+2,016	−8,658	−6,453
	9.0	R........	2.781	13,293	8,037	15,768	9,400	−3,788	+ 737	10.79	−2,016	−4,059	−5,805	−7,848
	10.0	F........	6.910	33,030	19,970	39,180	23,356	−9,411	+1,831	26.81	− 210	+2,240	−9,620	−7,170
	10.0	R........	3.090	14,770	8,930	17,520	10,444	−4,209	+ 819	11.99	−2,240	−4,510	−6,450	−8,720
Low incidence.	1.0	Combined	1.000	−4,810	+2,902	−5,624	+3,360	−1,362	+ 263	3.86	....	....	....	....
	1.0	F........	.413	1,987	1,199	2,323	1,388	− 563	+ 109	1.59	+ 22	+ 69	− 541	− 494
	1.0	R........	.587	2,823	1,703	3,301	1,972	− 799	+ 154	2.27	− 69	− 136	− 868	− 935
	4.0	F........	1.652	7,946	4,794	9.291	5,551	−2,250	+ 434	6.38	+ 88	+ 276	−2,164	−1,976
	4.0	R........	2.348	11,294	6,814	13,205	7,889	−3,198	+ 618	9.06	− 276	− 544	−3,472	−3,740
	5.0	F........	2.065	9,933	5,995	11,614	6,938	−2,813	+ 543	7.97	+ 110	+ 345	−2,705	−2,470
	5.0	R........	2.935	14,117	8,517	16,506	9,862	−3,997	+ 772	11.33	− 345	− 680	−4,340	−4,675
	6.0	F........	2.478	11,919	7,191	13,936	8,326	−3,375	+ 652	9.57	+ 132	+ 414	−3,246	−2,964
	6.0	R........	3.522	16,941	10,221	19,808	11,834	−4,797	+ 926	13.59	− 414	− 816	−5,208	−5,610
	7.0	F........	2.891	13,906	8,390	16,259	9,714	−3,938	+ 760	11.16	+ 154	+ 483	−3,787	−3,458
	7.0	R........	4.109	19,764	11,924	23,109	13,806	−5,596	+1,081	15.86	− 483	− 952	−6,076	−6,545

TABLE III.—*U. S. A.-27.*

FRONT UPPER SPAR—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section. Height.	Unrouted section. Width.	Routed. Flanges.	Routed. Web.	Factor of safety of design. At strut.	Factor of safety of design. In span.	Section areas. At strut.	Section areas. In span.	Weight in pounds.
	Inches.	*Inches.*	*Inches.*	*Inches.*					
6.0	6-1/4	1-1/16	5/16	5/16	12.12	6.00	6.64	2.42	17.5
7.0	6-1/4	1-1/4	3/8	11/32	14.17	6.97	7.81	2.83	20.5
8.0	6-1/4	1-3/8	11/32	3/8	15.57	8.06	8.59	3.28	23.3
9.0	6-1/4	1-1/2	7/16	7/16	16.87	8.95	9.37	3.66	25.9
10.0	6-1/4	1-1/2	1/2	1/2	16.87	10.10	9.37	4.12	28.1

Average area in routed portion=0.407 sq. in./F. S.

TABLE IV.—*U. S. A.-27.*

REAR UPPER SPAR—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section. Height.	Unrouted section. Width.	Routed. Flanges.	Routed. Web.	Factor of safety of design. At strut.	Factor of safety of design. In span.	Section areas. At strut.	Section areas. In span.	Weight in pounds.
	Inches.	*Inches.*	*Inches.*	*Inches.*					
6.0	5-3/8	11/32	1/4	9/32	19.56	6.00	5.21	1.86	13.5
7.0	5-3/8	1-1/8	5/16	5/16	22.54	7.05	6.05	2.19	15.9
8.0	5-3/8	1-7/32	3/8	11/32	24.40	8.01	6.55	2.50	17.8
9.0	5-3/8	1-9/32	7/16	3/8	25.65	8.98	6.88	2.81	19.6
10.0	5-3/8	1-1/2	1/2	3/8	29.82	10.06	8.06	3.14	22.2

Average area in routed portion=0.312 sq. in./F. S

TABLE V.—*U. S. A.-27.*

REAR UPPER SPAR—LOW INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
4.0	5 3/8	7/8	11/32	3/8	6.14	4.01	4.70	2.42	15.9
5.0	5 3/8	1 1/8	1/2	7/16	7.78	5.03	6.05	3.04	20.0
6.0	5 3/8	1 3/16	11/16	1/2	8.22	6.00	6.38	3.63	23.2
7.0	5 3/8	1 1/4	11/16	5/8	8.54	6.98	6.72	4.22	26.3

Average area in routed portion=.6046 sq. in./F. S.

TABLE VI.—*R. A. F.-15.*

FRONT UPPER SPAR—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
5.0	3 7/8	1 13/16	9/16	3/8	9.19	4.99	6.90	3.03	20.7
6.0	3 7/8	1 15/16	5/8	15/32	9.95	5.99	7.51	3.65	24.2
7.0	3 7/8	2 1/32	3/4	17/32	10.42	7.03	7.87	4.31	27.8
8.0	3 7/8	2 9/32	3/4	5/8	11.64	8.00	8.84	4.91	31.5
9.0	3 7/8	2 15/32	13/16	11/16	12.55	9.01	9.56	5.55	35.3
10.0	3 7/8	2 17/32	7/8	3/4	13.25	10.00	10.11	6.16	38.8

Average area in routed portion=.613 sq. in./F. S.

TABLE VII.—*R. A. F.-15.*

REAR UPPER SPAR.—HIGH INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
5.0	3	1 1/2	11/16	1/2	10.00	4.96	4.50	2.81	17.6
6.0	3	1 5/8	3/4	5/8	10.90	5.97	4.88	3.38	20.7
7.0	3	1 7/8	11/16	11/16	12.51	7.05	5.63	3.99	24.3
8.0	3	2	7/8	13/16	13.27	8.02	6.00	4.56	27.4
9.0	3	2 1/4	13/16	7/8	14.81	8.98	6.75	5.12	30.8
10.0	3	2 3/8	1	15/16	15.70	10.00	7.13	5.69	33.9

Average area in routed portion=.568 sq. in./F. S.

TABLE VIII.—*R. A. F.-15.*

REAR UPPER SPAR.—LOW INCIDENCE CONDITIONS.

Loading by L. F.	Unrouted section.		Routed.		Factor of safety of design.		Section areas.		Weight in pounds.
	Height.	Width.	Flanges.	Web.	At strut.	In span.	At strut.	In span.	
	Inches.	*Inches.*	*Inches.*	*Inches.*					
4.0	3	1 1/2	11/16	3/4	5.66	4.04	4.50	3.28	19.9
5.0	3	1 7/8	23/32	7/8	7.06	4.98	5.62	4.06	24.7
6.0	3	2 1/4	3/4	1 1/32	8.40	6.00	6.75	4.92	29.9
7.0	3	2 1/2	13/16	1 1/4	9.31	7.05	7.50	5.78	34.7

Average area in routed portion=.8174 sq. in./F. S.

TABLE IX.—*U. S. A.-27.*

OUTER STRUTS.

Load factor.	Strut.	High incidence. Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.	Low incidence. Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.
			Pounds.				*Pounds.*		
1	Combined....	1.00	−386	....	....	1.000	−389	....	....
1	F...........	.72	278	61.75	....	.065	25	61.75	....
1	R...........	.28	108	62.62	....	.935	364	62.62	....
4	F...........	2.88	1,112	61.75	3.64	.260	101	61.75	1.10
4	R...........	1.12	432	62.62	2.30	3.740	1,455	62.62	4.23
5	F...........	3.60	1,390	61.75	4.07	.325	126	61.75	1.23
5	R...........	1.40	540	62.62	2.57	4.675	1,819	62.62	4.72
6	F...........	4.32	1,668	61.75	4.46	.390	152	61.75	1.35
6	R...........	1.68	648	62.62	2.82	5.610	2,182	62.62	5.18
7	F...........	5.04	1,945	61.75	4.81	.455	177	61.75	1.45
7	R...........	1.96	757	62.62	3.04	6.545	2,546	62.62	5.59
8	F...........	5.76	2,223	61.75	5.15	....	....	....	....
8	R...........	2.24	865	62.62	3.23	....	....	....	....
9	F...........	6.48	2,501	61.75	5.46	....	....	....	....
9	R...........	2.52	973	62.62	3.45	....	....	....	....
10	F...........	7.20	2,779	61.75	5.76	....	....	....	....
10	R...........	2.80	1,081	62.62	3.64	....	....	....	....

TABLE X.—*R. A. F.-15.*

OUTER STRUTS.

Load factor.	Strut.	High incidence. Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.	Low incidence. Load per cent of L. truss.	Compression in strut.	Length.	Areas in square inches.
			Pounds.				*Pounds.*		
1	Combined....	1.000	−386	....	....	1.000	−389	....	....
1	F...........	.691	−267	64 1/8	....	.413	161	64 1/8	....
1	R...........	.309	119	65	....	.587	228	65	....
4	F...........	2.764	1,067	64 1/8	3.71	1.652	643	64 1/8	2.88
4	R...........	1.236	477	65	2.51	2.348	913	65	3.47
5	F...........	3.455	1,334	64 1/8	4.14	2.065	803	64 1/8	3.22
5	R...........	1.545	596	65	2.80	2.935	1,142	65	3.88
6	F...........	4.146	1,600	64 1/8	4.54	2.478	964	64 1/8	3.52
6	R...........	1.854	716	65	3.07	3.522	1,370	65	4.25
7	F...........	4.837	1,867	64 1/8	4.90	2.891	1,125	64 1/8	3.80
7	R...........	2.163	835	65	3.32	4.109	1,598	65	4.60
8	F...........	5.528	2,134	64 1/8	5.25	....	....	....	....
8	R...........	2.472	954	65	3.55	....	....	....	....
9	F...........	6.219	2,400	64 1/8	5.56	....	....	....	....
9	R...........	2.781	1,073	65	3.76	....	....	....	....
10	F...........	6.910	2,667	64 1/8	5.86	....	....	....	....
10	R...........	3.090	1,193	65	3.97	....	....	....	....

TABLE XI.—*Different designs for the rear upper spar of the U. S. A.-27 wing at 10 F. S.*

HIGH INCIDENCE CONDITIONS.

Unrouted section. Height.	Width.	Routed portion. Flanges.	Web.	Factor of safety of design. At strut.	In span.	Moment of inertia. At strut.	In span.	Cross-section areas. At strut.	In span.	Area ratio.	Weight of spar in pounds.	Deflection of spar in Bay 1-2.
Inches.	*Inches.*	*Inches.*	*Inches.*									
5 3/8	2 1/16	7/16	1/4	45.40	9.92	30.00	14.31	12.43	3.15	0.253	25.9	0.389
5 3/8	1 1/2	1/2	3/8	29.82	10.06	19.44	11.59	8.06	3.14	.390	22.2	.480
5 3/8	1	11/32	7/16	20.20	10.00	12.96	9.82	5.38	3.09	.574	19.7	.567
5 3/8	3/4	3/8	1/2	15.16	10.07	9.72	8.51	4.03	3.06	.758	18.4	.653
5 3/8	39/64	(1)	(1)	12.34	10.10	7.90	7.90	3.28	3.28	1.000	18.8	.704

[1] No routing.

Area ratio is the ratio of the area of the routed section to that of the unrouted section.

DISCUSSION.

1. The characteristics of the spars designed, listed in Tables III, IV, V, VI, VII, and VIII, show that the area varies directly as the load factor.

2. It will be observed that the weight of the spar varies with the load factor, but not directly with it, as the curves shown in figure 2 take the form $Ax + By = K$. For this particular case, K is undoubtedly the excess area added at the strut points and compression ribs to provide sufficient area for the fittings, to transfer stresses from the ribs, struts, and wires to the spars and to each other, and to stiffen the spars for drag bending. Doubling the load will not double the weight of the spar, though the error in any case is on the safe side, and for small increases in the load factor the error would be so small as to be negligible.

3. The deflection of a spar with constant load and span varies inversely as the moment of inertia, so that an unrouted spar shows greater deflection for a given load than a routed spar of the same area and center height.

4. While the computations made during this investigation have not been as comprehensive in regard to the effect on the F. S. of variations in the moment of inertia as might be desired, they indicate that for a given load and with constant area and center height small variations in the moment of inertia have little if any effect upon the F. S.; and that with constant load, constant span, constant area of the routed portion and center height the moment of inertia may vary at will with little effect upon the F. S., so long as the ratio of the area of the routed portion to the area of the unrouted portion remains between 50 per cent and 80 per cent. However, the characteristics of a spar, a typical case being listed in Table XI, would indicate that as the area ratio approaches 80 per cent the best spar in regard to minimum weight is obtained.

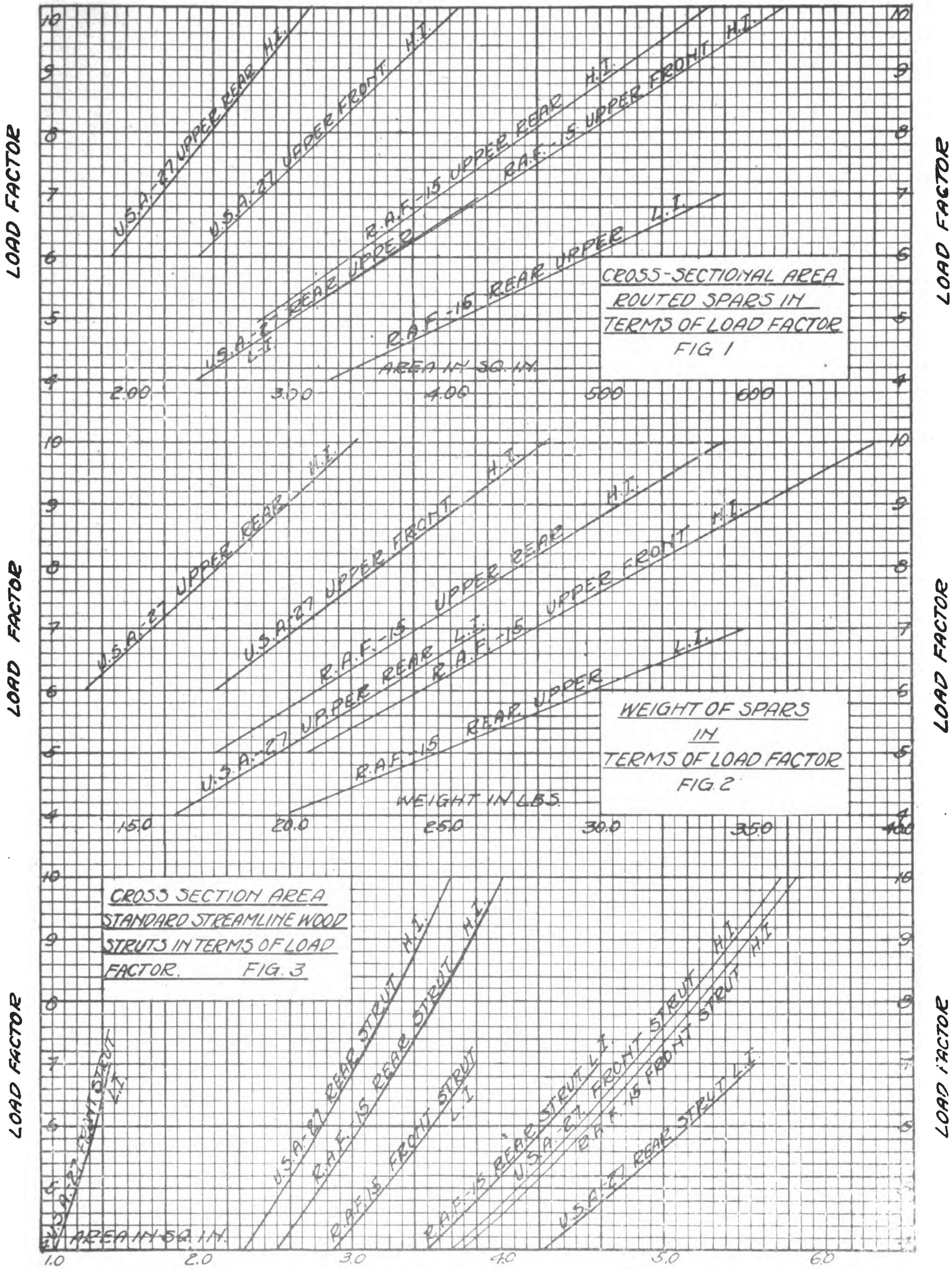
5. In many cases, more especially with the thicker wing sections, when it is desired to amend a design for small increases in useful load, the area of the spar can be increased by decreasing the routing up to a point where the ratio of the area of the routed portion to that of the unrouted portion equals 75 per cent to 80 per cent, thus keeping the spar as light as possible and effecting a saving in the redesign of ribs, fittings, etc.

6. According to the formula for struts, the area varies with the length and with the square root of the load.

7. The curves for the area in terms of the load factor (see fig. 3) show that with the length constant the curve for the area in terms of the load factor is nearly a straight line.

8. If the area of a strut with constant length be increased in proportion to the load factor, the error will be on the safe side in any case, and for small increases in the load factor the error will be negligible.

9. The curves in figure 2 show that the U. S. A.–27 section has lighter spars than the R. A. F.–15 section, and the curves in figure 3 show that the U. S. A.–27 section has a lighter front strut, while the R. A. F.–15 section has a lighter rear strut, due to the difference in center of pressure travel. However, computations will show that the two struts with the R. A. F.–15 section are but very little lighter than those with the U. S. A.–27 section at the load factors of design for pursuit airplanes. With the thicker wing section, the ribs and compression struts would be heavier, but the difference in weight would be small, as it would be due mostly to increased web area. Because of the greater spar height in the U. S. A.–27 section it is possible, in spite of the increased center of pressure travel, to design spars so much lighter than with the R. A. F.–15 section as to overcome the increased weights due to heavier struts, ribs, and compression struts and to effect a considerable saving in the structural weight of the wings.


LOAD FACTOR
CROSS-SECTIONAL AREA
ROUTED SPARS IN
TERMS OF LOAD FACTOR
FIG 1
U.S.A.-27 UPPER REAR H.I.
U.S.A.-27 UPPER FRONT H.I.
R.A.F.-15 UPPER REAR H.I.
R.A.F.-15 UPPER FRONT H.I.
U.S.A.-27 REAR UPPER L.I.
R.A.F.-15 REAR UPPER L.I.
AREA IN SQ. IN.
2.00
3.00
4.00
500
600
WEIGHT OF SPARS
IN
TERMS OF LOAD FACTOR
FIG. 2
U.S.A.-27 UPPER REAR H.I.
U.S.A.-27 UPPER FRONT H.I.
R.A.F.-15 UPPER REAR H.I.
R.A.F.-15 UPPER FRONT H.I.
U.S.A.-27 UPPER REAR L.I.
R.A.F.-15 REAR UPPER L.I.
WEIGHT IN LBS.
15.0
20.0
25.0
30.0
35.0
40.0
CROSS SECTION AREA
STANDARD STREAMLINE WOOD
STRUTS IN TERMS OF LOAD
FACTOR. FIG. 3
U.S.A.-27 FRONT STRUT L.I.
U.S.A.-27 REAR STRUT H.I.
R.A.F.-15 REAR STRUT H.I.
R.A.F.-15 FRONT STRUT L.I.
R.A.F.-15 REAR STRUT L.I.
U.S.A.-27 FRONT STRUT H.I.
R.A.F.-15 FRONT STRUT H.I.
U.S.A.-27 REAR STRUT L.I.
AREA IN SQ. IN.
1.0
2.0
3.0
4.0
5.0
6.0

Figs. 1, 2, and 3